Mechanically Pumped Fluid Loop (MPFL) Technologies for Thermal Control of Future Mars Rovers

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OUTLINE

• Mars Missions

• Thermal Control Challenges

• Mars Science Laboratory Thermal control

• Mechanically Pumped Fluid Loop (MPFL) Technology Development

• Conclusions
Mars Exploration Rovers (2003)

- 90-sol science missions
- Equatorial landing sites
- Deep temp. swings (-90 to 10°C)

Lander after the Egress of Spirit Rover at Gusev Crater (sol 19)

MER Rover (2003)

Spirit Rover self portrait (Two Earth years later)
Mars Exploration Program (2004)

Launch Year

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<tbody>
<tr>
<td>Mars Telesat Orbiter</td>
<td>Scout</td>
<td>Mars Sample Return</td>
<td>Scout</td>
<td>Deep Drill Lander</td>
<td>Scout</td>
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<tr>
<td>Mars Science Laboratory</td>
<td>Astrobiology Field Laboratory</td>
<td>OR</td>
<td>OR</td>
<td>Network Landers</td>
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## Draft Mars Exploration Architecture

(Under consideration, not approved)

### 2009 - 2024

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<tr>
<td></td>
<td>Mars Science Laboratory (MSL)</td>
<td>Scout or Mars Science Orbiter with Telecom</td>
<td>Midrovers or Astrobiology Field Laboratory (AFL)</td>
<td>Scout</td>
<td>Planetary Evolution And Meteorology Network</td>
<td>Mars Sample Return (MSR) Orbiter and Return Capsule</td>
<td>Mars Sample Return (MSR) Mobile</td>
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</table>

### Other Options
- Scout or Mars Science Orbiter with Telecom
- Midrovers or Astrobiology Field Laboratory (AFL)
- Scout
- Planetary Evolution And Meteorology Network
- Mars Sample Return (MSR) Orbiter and Return Capsule
- Mars Sample Return (MSR) Mobile
Thermal Control Challenges for Future Mars Missions

- Thermal control requirements of many of the future NASA Mars science missions are very demanding

- Mars Surface Missions
  - Extreme diurnal thermal environment (-129 C to 40 C for Mars)
  - Thermal management of Radioisotope Power Sources (RPS)
  - Rover mobility challenges to thermal control (configuration, dust etc)
  - Science Instrument thermal requirements
Mars Rovers – Past, Present, and Future

Sojourner (1996), 12 kg
Aerogel, Passive TC

MER (2003), 180 kg
Aerogel, Heat Switch

MSL (2009), ~ 500 kg
Pumped Fluid Loops

Issues:
• Large Thermal Loads (~2 kWt)
• Long Life (~2 Earth Years)
The Surface System fluid loop (HRS-S) would use CFC-11 as the working fluid and has an operating temperature range of -100 to +100°C in various components of the system.

Cruise HRS (HRS-C) would use CFC-11 (in the 0 to 80°C range).
MPFL on MSL

Surface System Fluid Loop (SHRS)

Loop controls *both* Avionics and Payload zones

Cruise HRS Radiators

MMRTG

Cruise Pumped Fluid Loop (CHRS)

Cruise Radiator (split flow)

Descent Stage: TWTA, SDST, DPAM, DPA & DPFA

Rover PMP & RAMP HXCH

Surface System Heat Exchanger

Cruise Stage: CIPA, CPA, CPAM, DSS

Transfer Lines

Windbreaker

Windbreaker
Mechanically Pumped Cooling Loops

Description

- Mechanically pumped single-phase (CFC-11) cooling loop was first used on Mars Pathfinder (1996) and

- A similar system was successfully flown on two MER spacecraft (2003)

- A pump assembly of 7 kg uses CFC-11 to remove ~160 W from spacecraft electronics to an external radiator
## Comparison of MPFL’s on MSL and MER

<table>
<thead>
<tr>
<th>MER HRS</th>
<th>MSL HRS</th>
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</thead>
<tbody>
<tr>
<td><strong>One Fluid Loop</strong></td>
<td><strong>Two Fluid Loops</strong></td>
</tr>
<tr>
<td><strong>Cruise Stage HRS</strong></td>
<td><strong>Cruise Stage HRS</strong></td>
</tr>
<tr>
<td>• Removed ~200 W</td>
<td>Removes RTG waste heat ~2000 W</td>
</tr>
<tr>
<td>• CFC-11 in the -80 to 50 C range</td>
<td>Fluid (CFC-11) in the 0 to 100 C range;</td>
</tr>
<tr>
<td>• Pump flow rate 0.75 lpm</td>
<td>Pump in the of -35 to 50 C range</td>
</tr>
<tr>
<td>• Pump &amp; valves operating range of -35 to 50 C</td>
<td>Pump flow rate of ~1.5 lpm</td>
</tr>
<tr>
<td><strong>Rover HRS</strong></td>
<td><strong>Rover HRS</strong></td>
</tr>
<tr>
<td>• Pump flow rate of 0.75 lpm</td>
<td>Recovers RTG waste heat on Mars surface ~350 W</td>
</tr>
<tr>
<td>• Passive splitting-type thermal control valve (wax based actuator)</td>
<td>• Fluid (CFC-11) in -100 to +100 C range; pump &amp; valves -40 to 100 C range</td>
</tr>
<tr>
<td>• One-year life time</td>
<td>• Pump flow rate of 0.75 lpm</td>
</tr>
<tr>
<td></td>
<td>• Passive mixing and splitter-type thermal control valve (liquid-based actuator)</td>
</tr>
<tr>
<td></td>
<td>• Three-year life time</td>
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# Mechanical Pumps for MPFL

<table>
<thead>
<tr>
<th>Engineering Pump</th>
<th>Fluid</th>
<th>AFT Range, °C</th>
<th>Flow Rate, lpm</th>
<th>Pr. Rise, psid</th>
<th>Pump Power, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPF EM Pump (1995)</td>
<td>CFC-11</td>
<td>-35 to 50</td>
<td>0.75</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>MER EM Pump (2002)</td>
<td>CFC-11</td>
<td>-35 to 50</td>
<td>0.75</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>MSL High Flow Pump, (2003)</td>
<td>Water</td>
<td>0 to 120</td>
<td>1.125</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>MSL Rover Pump (2005)</td>
<td>CFC-11</td>
<td>-40 to 100</td>
<td>0.75</td>
<td>6</td>
<td>10</td>
</tr>
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Mechanical Pumps and Valves for MPFL

MPF EM Pump (1995)

MSL EM Rover Pump (2005)


MSL Thermal Control Valve (2006)
Pumped Fluid Loop System Life Tests

- MER EM pump has been operating in a test bed for over 31,000 hours in CFC-11 in ambient conditions (~20 C)
- An MSL High flow pump designed for has been life tested for 2900 hrs at 120 C with water and 3000 hours in CFC-11 at 90 C
- An MSL EM rover pump has been operating in a life test bed for over 9000 hours in simulated MSL rover environment
Mechanical Fittings for MPFL

Mechanical Joints

- Up to 25 mechanical joints will be used on MSL rover MPFL. In order to keep the leak rate small, Omnisafe (VCR style) joints are being qualified for use on MSL. These joints with 'torque suppression' system have a leak rate about 3 to 4 order of magnitude less than A-N fittings and can be used for tens of mate and demates.

Interface Weld Fittings

- Because of the use of aluminum tubing and SS joints, several al-ss inertial weld fittings used in the MSL MPFL. These fittings have been qualified and life tested in CFC-11 fluid at 100 C.
Chemical Compatibility MPFL Materials

- Several samples of MSL MPFL tube material are evaluated for chemical compatibility with CFC-11 at 100°C.

- Chemical compatibility tests for underway for evaluation of long-term degradation of fluids and material for over two years.
Conclusions

• Mechanically pumped fluid loop has been the basis of thermal control architecture for the last two Mars lander and rover missions and is the key part of the MSL thermal architecture.

• Several MPFL technologies are being developed for the MSL rover include long-life pumps, thermal control valves, mechanical fittings for use with CFC-11 at elevated temperatures of ~100°C.

• Over three years of life tests and chemical compatibility tests on these MPFL components show that MPFL technology is mature for use on MSL.

• The advances in MPFL technologies for MSL Rover will benefit any future MPFL applications on NASA’s Moon, Mars and Beyond Program.